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Smith

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[54] **REAL-TIME KINEMATIC INTEGRITY ESTIMATOR AND MONITOR**

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[73] Assignee: **Trimble Navigation Limited**, Sunnyvale, Calif.

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[22] Filed: **Jul. 7, 1997**

[51] **Int. Cl.**[6] **G01S 05/02**; H04B 7/185

[52] **U.S. Cl.** **342/357**; 701/213

[58] **Field of Search** 342/357; 701/213

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Dr. Nicholas C. Talbot, "Compact Data Transmission Standard for High–Precision GPS", *Journal of the Institute of Navigation*, pp. 1–10, (Sep./1996).

U.S. Patent Application No. 08/252,681, filed Jun. 2, 1994, entitled "Integrity Monitoring of Differential Satellite Positioning System Signals".

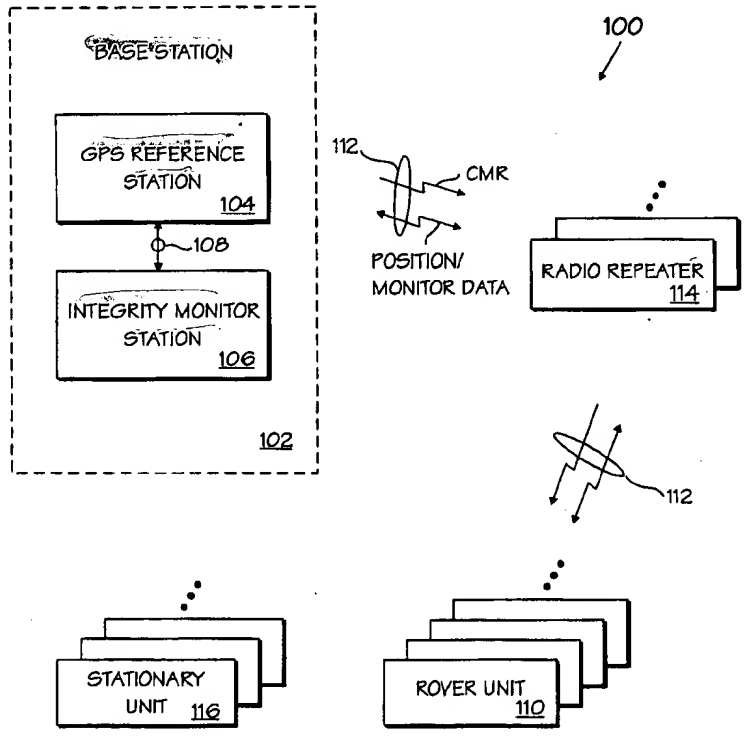
Primary Examiner—Mark Hellner

Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

[57] **ABSTRACT**

A first receiver computes its position using data from sources chosen according to conditions at a second receiver and reference data. The computed position is compared with a known position. The data may be GPS positioning data from satellites and/or pseudolites and the reference data may be RTK GPS data provided by an RTK GPS reference station. The conditions at the second receiver generally correspond to satellite constellations and other parameters and the position of the first receiver may be computed by configuring the first receiver to mimic the conditions at the second receiver. The comparison of the computed position to the known position may result in an error measurement which may be used to initiate an alert condition. In a further embodiment, a receiver has first circuitry configured to compute its position using data from sources chosen according conditions at a remote receiver and reference data. The receiver may further include second circuitry for comparing the computed position with a known position. The first circuitry may include a GPS engine which is configured to compute the position from GPS data derived from GPS satellites and/or pseudolites. In yet another embodiment, a system includes a first unit and a second unit, the second unit being configured to compute its position using data from sources chosen according to conditions at the first unit and reference data. The system may also include a reference unit configured to provide RTK GPS reference data to the second unit.

34 Claims, 9 Drawing Sheets



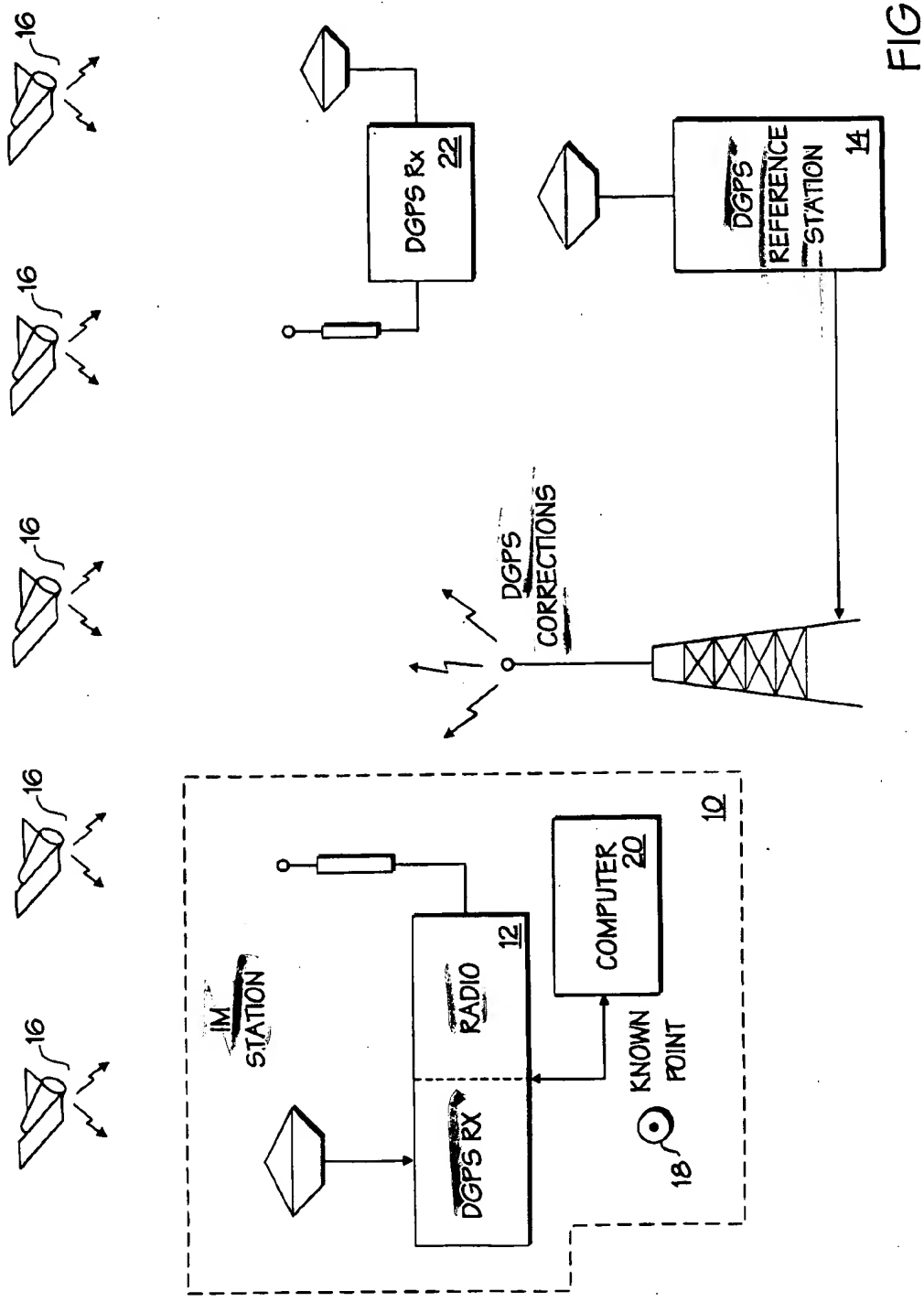

16
16
16
16
16
DGPS Rx
22
DGPS
REFERENCE
STATION
14
DGPS
CORRECTIONS
10
COMPUTER
20
IM
STATION
RADIO
12
DGPS RX
KNOWN
POINT
18

FIG. 1

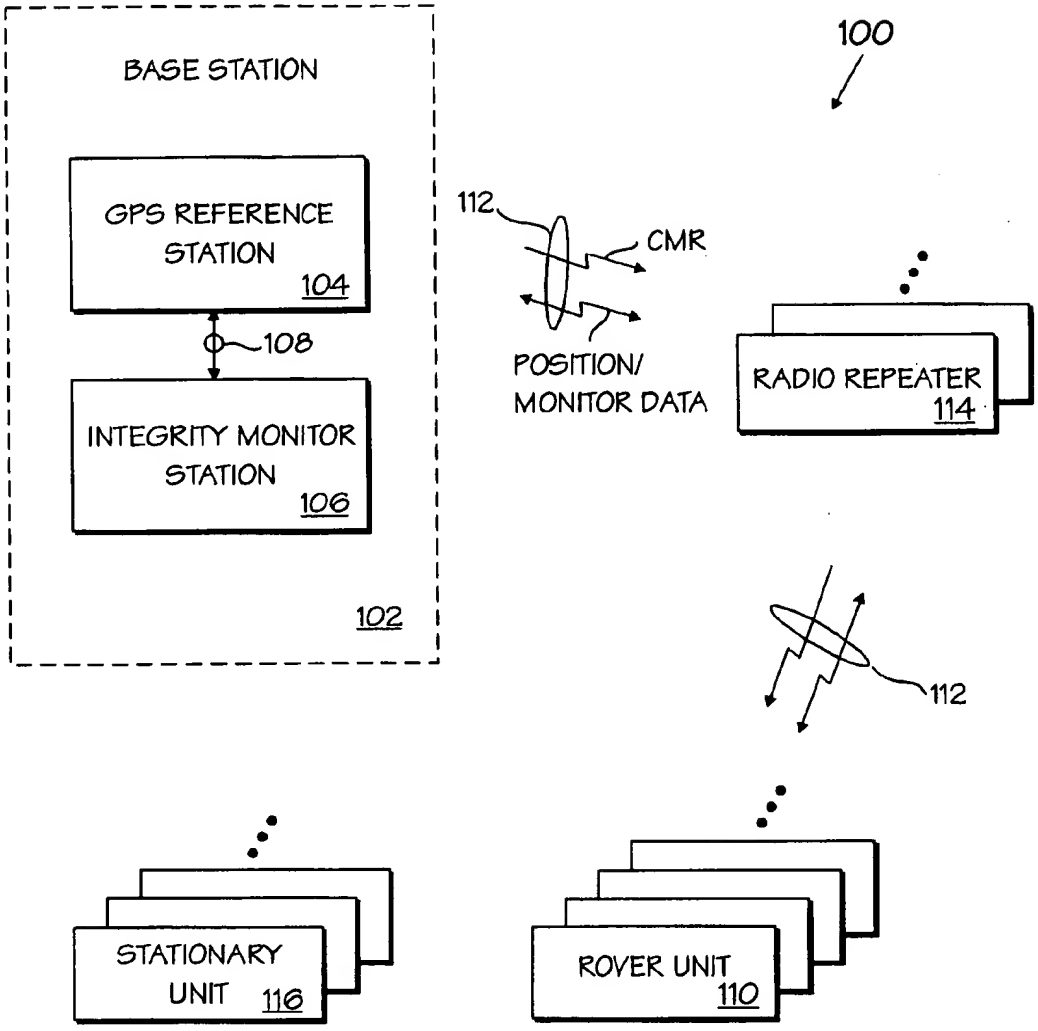

BASE STATION
GPS REFERENCE STATION
104
108
INTEGRITY MONITOR STATION
106
102
100
112
CMR
POSITION/ MONITOR DATA
RADIO REPEATER
114
112
STATIONARY UNIT
116
ROVER UNIT
110

Fig. 2

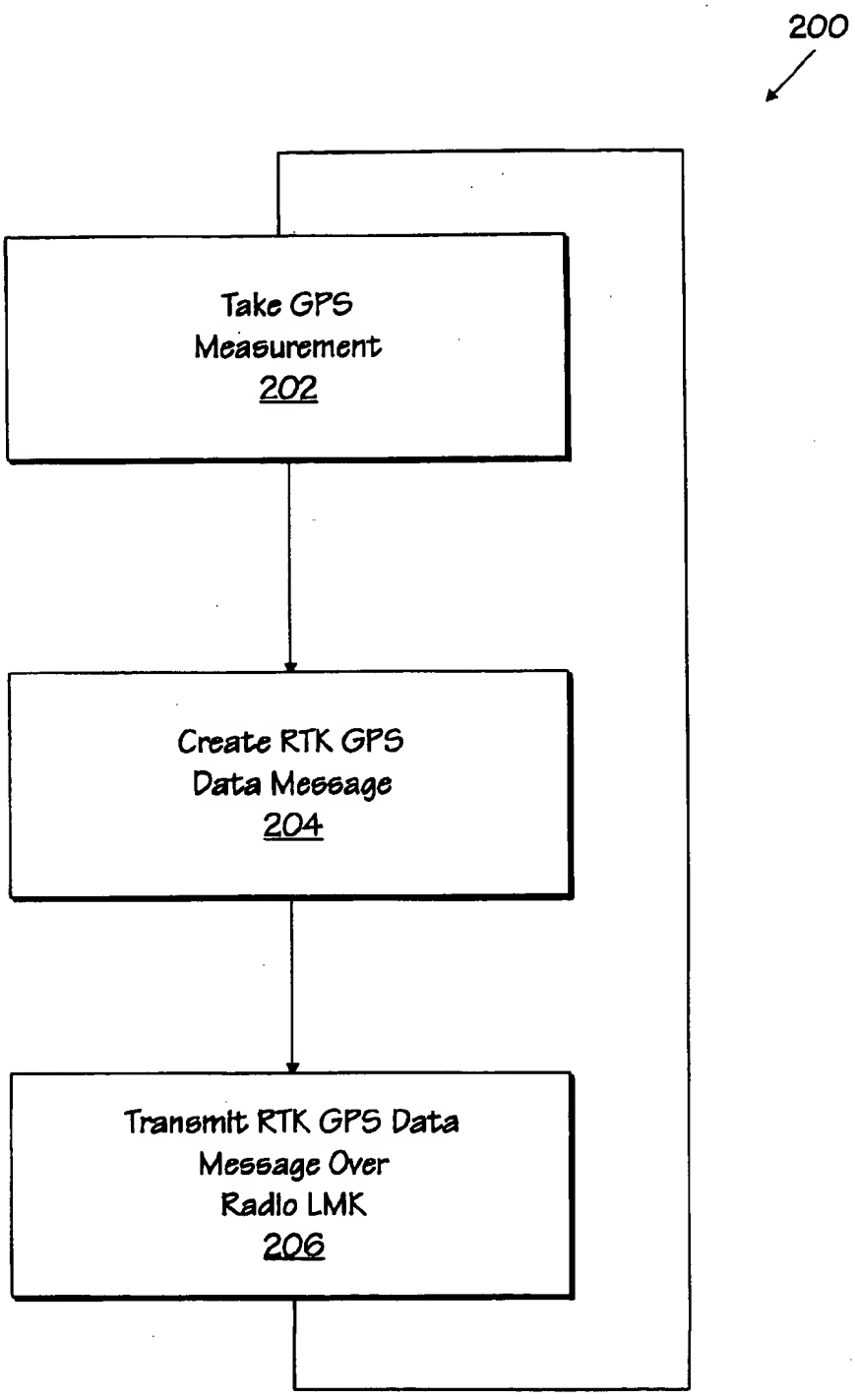

200
Take GPS Measurement 202
Create RTK GPS Data Message 204
Transmit RTK GPS Data Message Over Radio LMK 206

Fig. 3

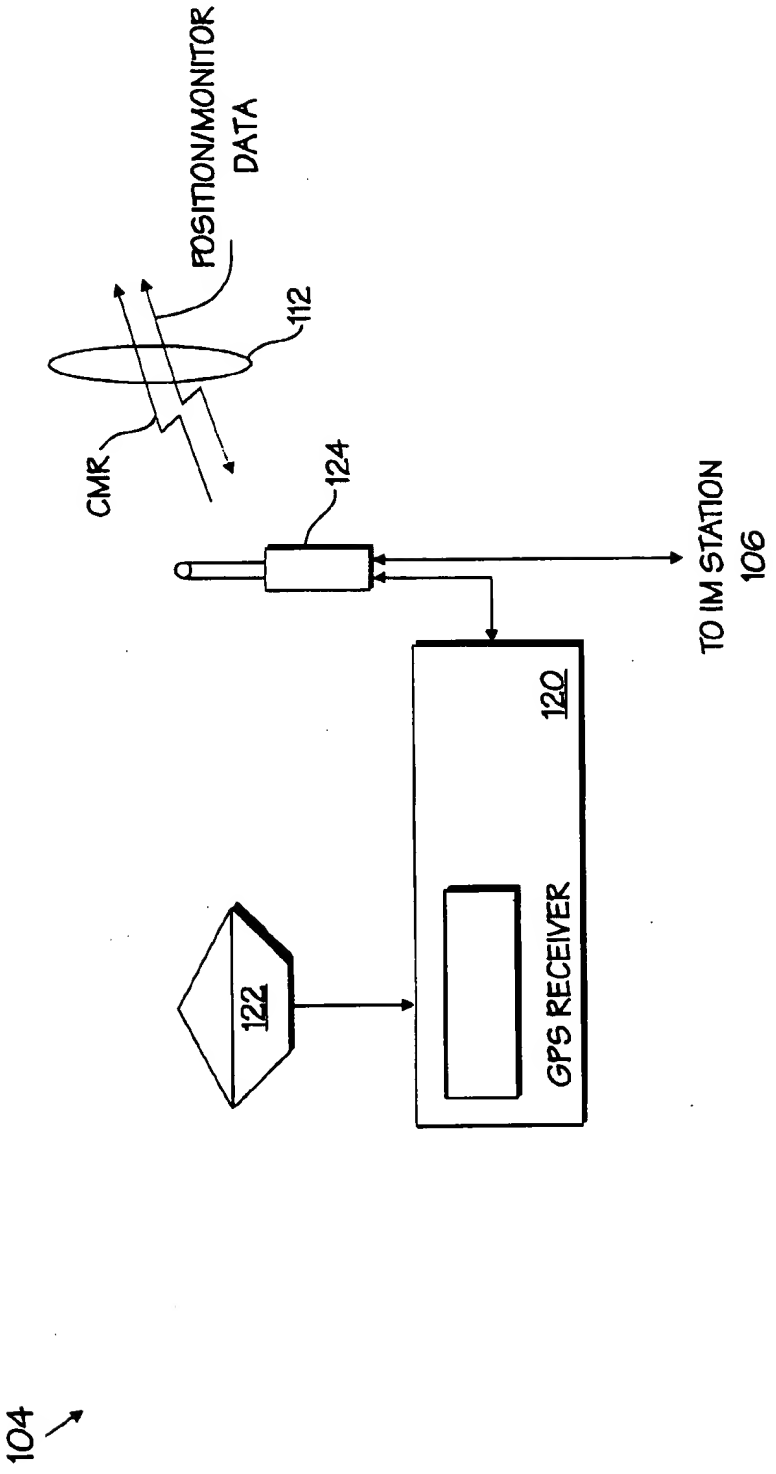

POSITION/MONITOR DATA
112
CMR
124
TO IM STATION 106
120
GPS RECEIVER
122
104
KNOWN POINT

FIG. 4

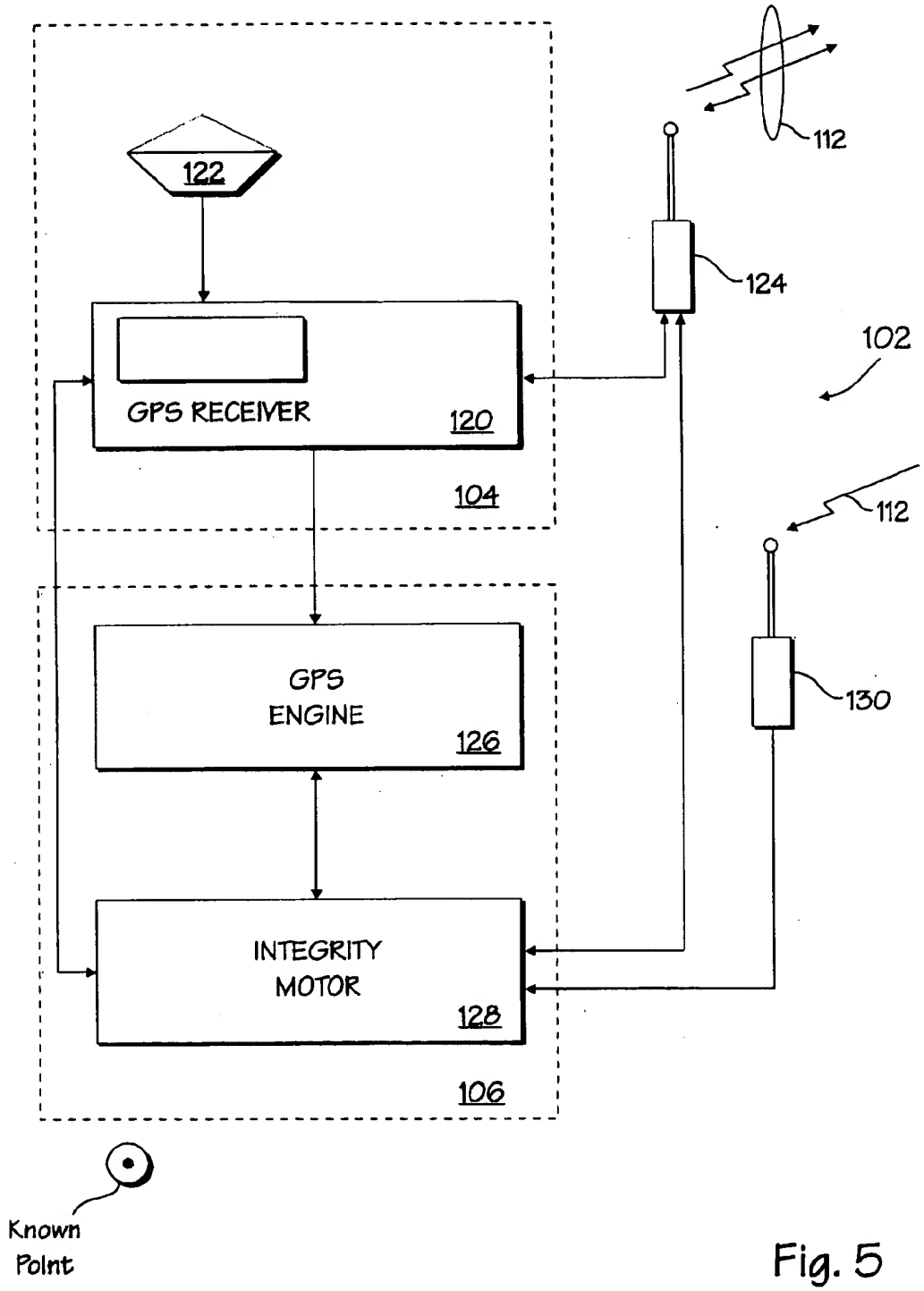

122
GPS RECEIVER
120
104
GPS
ENGINE
126
INTEGRITY
MOTOR
128
106
Known
Point
112
124
102
112
130

Fig. 5

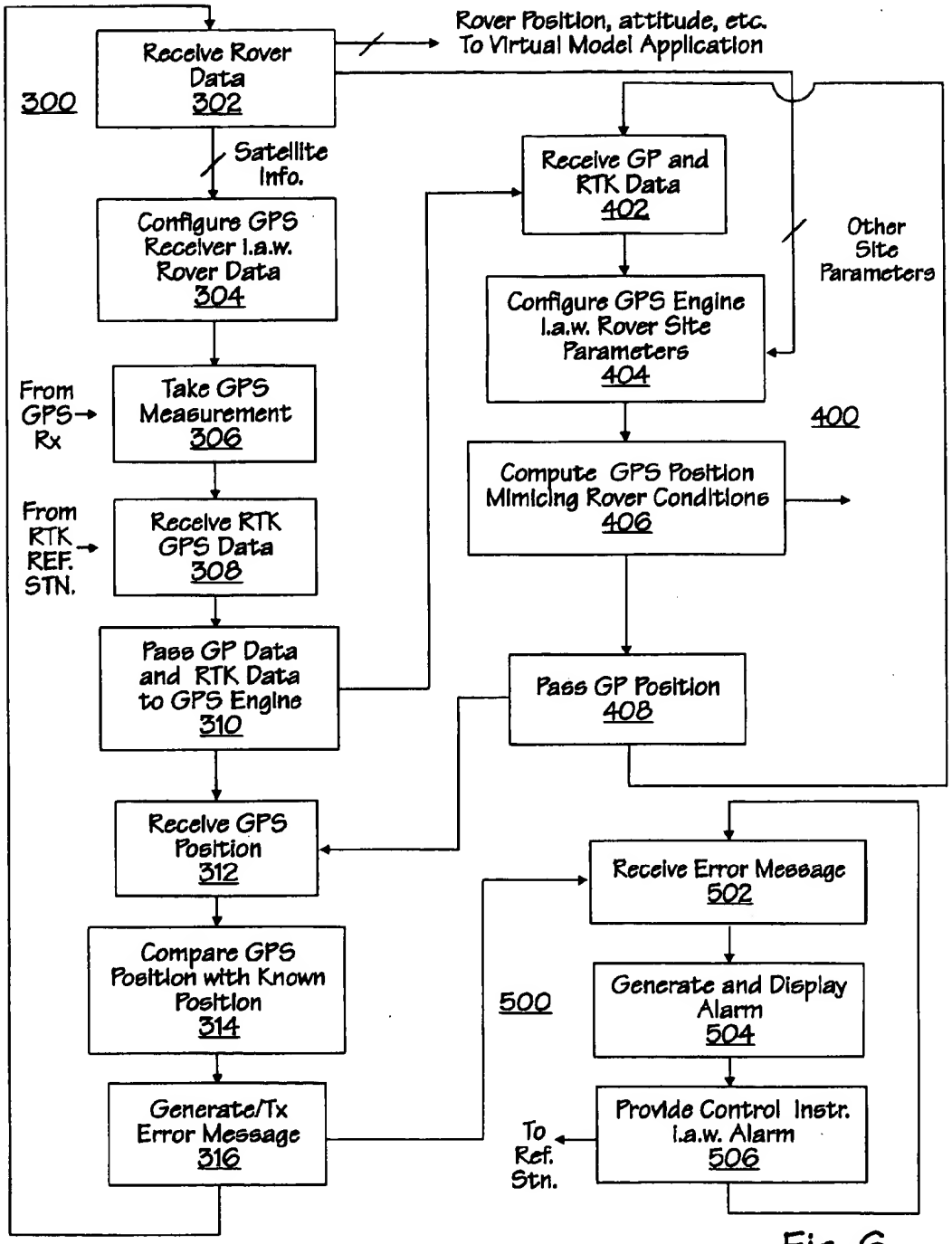

Rover Position, attitude, etc. To Virtual Model Application
Receive Rover Data 302
300
Satellite Info.
Configure GPS Receiver l.a.w. Rover Data 304
From GPS Rx
Take GPS Measurement 306
From RTK REF. STN.
Receive RTK GPS Data 308
Pass GP Data and RTK Data to GPS Engine 310
Receive GPS Position 312
Compare GPS Position with Known Position 314
Generate/Tx Error Message 316
Receive GP and RTK Data 402
Other Site Parameters
Configure GPS Engine l.a.w. Rover Site Parameters 404
400
Compute GPS Position Mimicing Rover Conditions 406
Pass GP Position 408
Receive Error Message 502
500
Generate and Display Alarm 504
Provide Control Instr. l.a.w. Alarm 506
To Ref. Stn.

Fig. 6

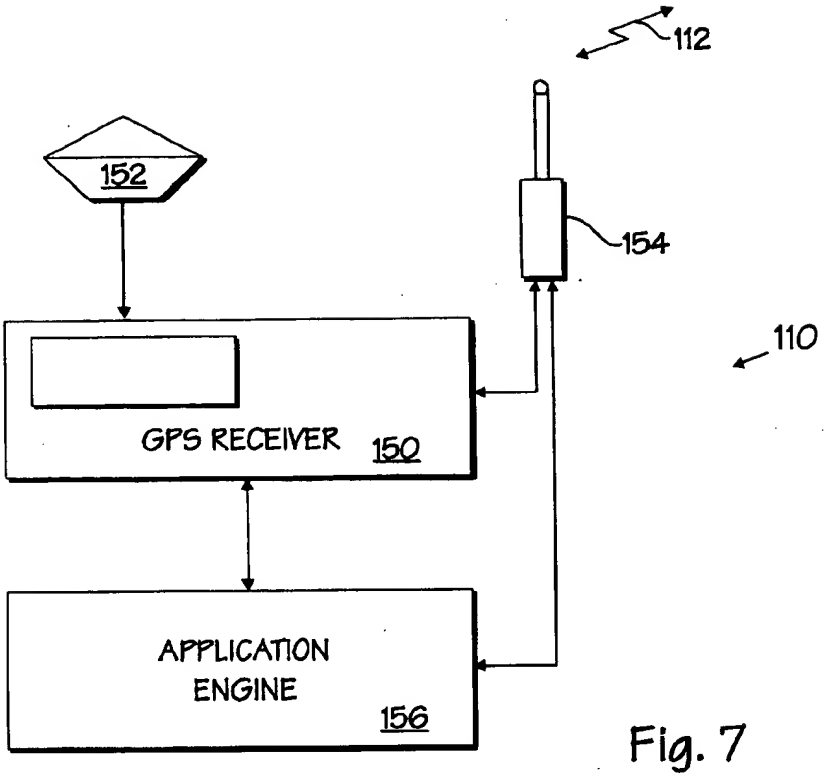

112
152
154
110
GPS RECEIVER 150
APPLICATION ENGINE 156

Fig. 7

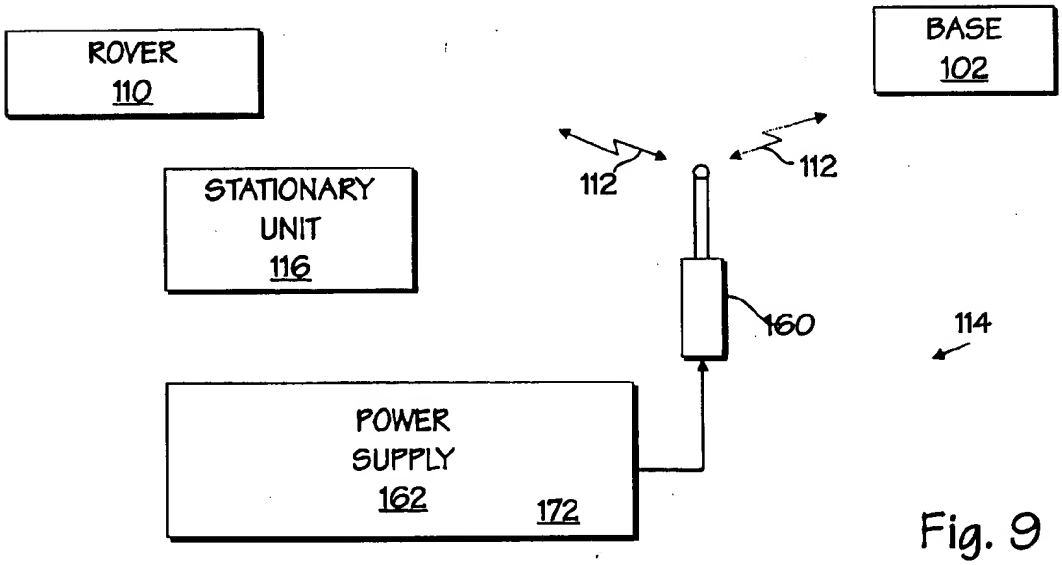

ROVER 110
BASE 102
112
112
STATIONARY UNIT 116
160
114
POWER SUPPLY 162
172

Fig. 9

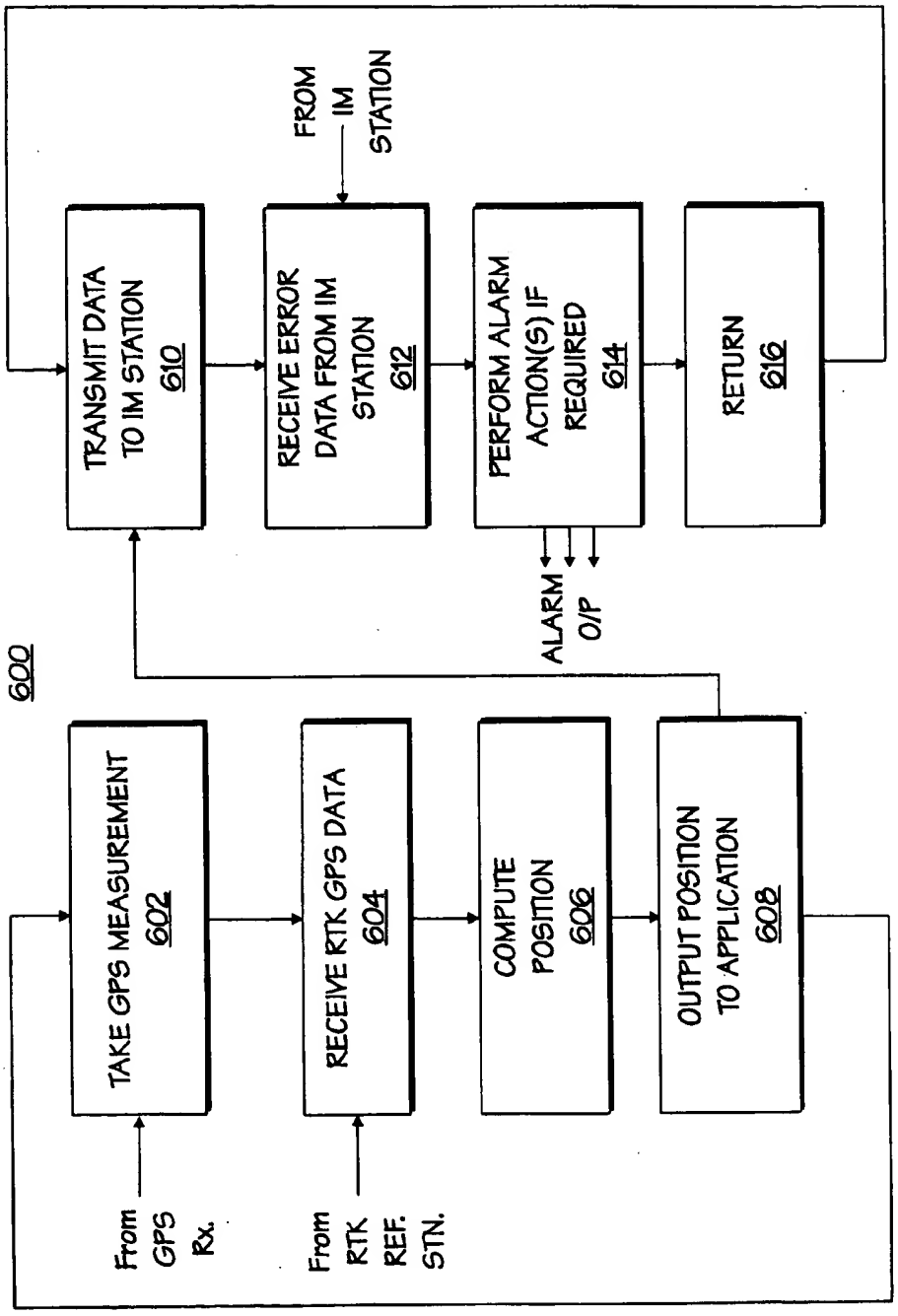

600
TAKE GPS MEASUREMENT 602
RECEIVE RTK GPS DATA 604
COMPUTE POSITION 606
OUTPUT POSITION TO APPLICATION 608
From GPS Rx.
From RTK REF. STN.
TRANSMIT DATA TO IM STATION 610
RECEIVE ERROR DATA FROM IM STATION 612
PERFORM ALARM ACTION(S) IF REQUIRED 614
RETURN 616
FROM IM STATION
ALARM O/P

Fig. 8

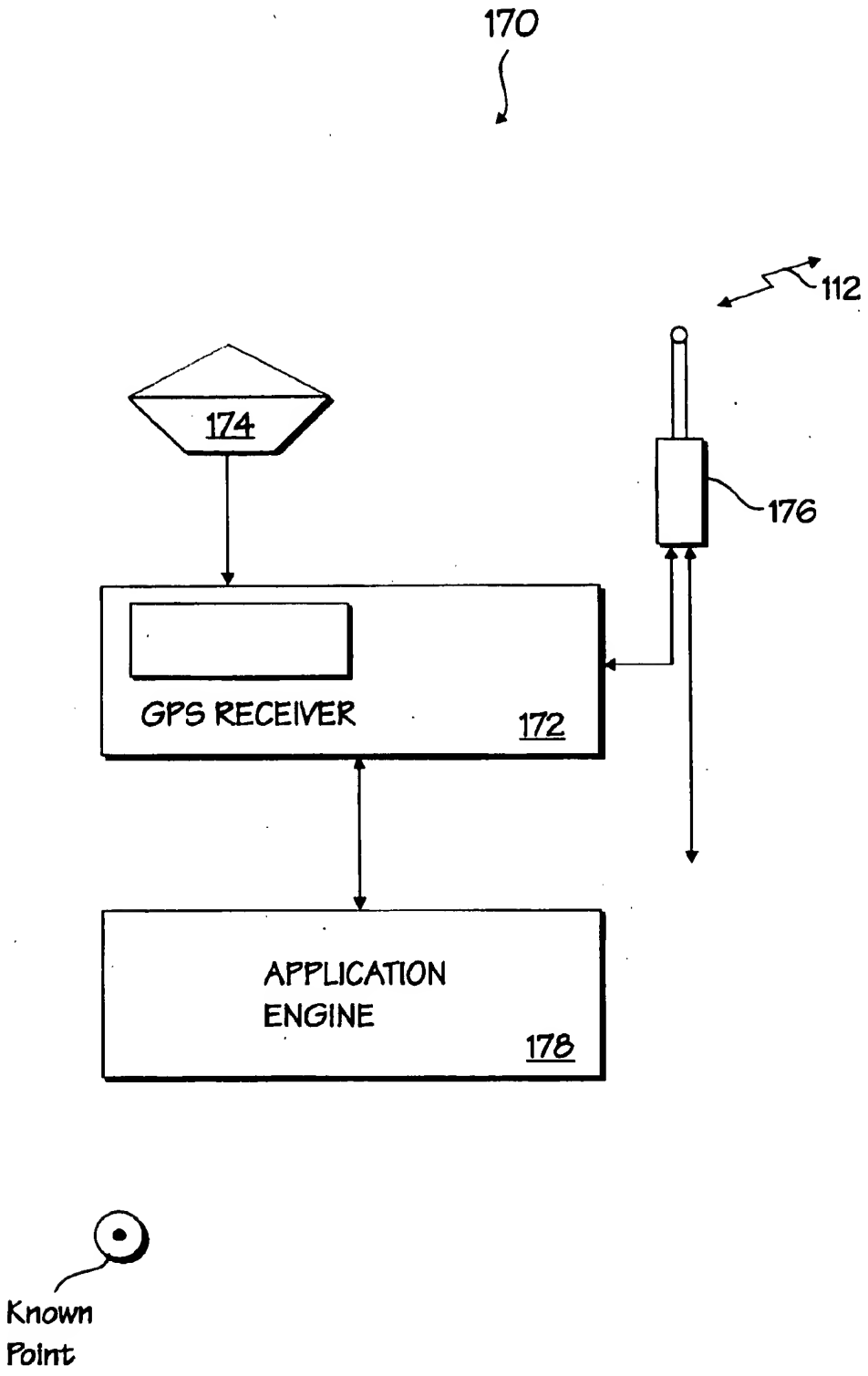

170
112
174
176
GPS RECEIVER
172
APPLICATION
ENGINE
178
Known
Point

Fig. 10

REAL-TIME KINEMATIC INTEGRITY ESTIMATOR AND MONITOR

FIELD OF THE INVENTION

The present invention relates to precise positioning systems and, more particularly, to real-time kinematic positioning systems utilizing Global Positioning System (GPS) receiver stations.

BACKGROUND

To assist sea, air, and land navigation and other purposes, the United States Government has placed a number of satellites in orbit around the Earth in such a manner that, from any point on the Earth, a user operating a roving receiver may have a line of sight to at least four satellites. This system is referred to as the Global Positioning System (GPS). A GPS receiver receives GPS data from the satellites; from the GPS data the roving receiver can determine its position. The GPS data includes data regarding the position of the satellite. However, the GPS data is corrupted by the U.S. Government in order to degrade the accuracy of calculations performed. Such errors are easily eliminated using the proper decoding algorithms and codes; however, such information is only available to the U.S. Military. Also, atmospheric and meteorological conditions, electromagnetic interference from terrestrial sources and other satellites, kinematic motion or orientation of the roving receiver and other uncertainties further degrade the signals.

To ameliorate this problem, land-based reference stations at fixed, known locations have been erected to receive satellite transmissions and interpret the signals to generate measurement corrections, also referred to as DGPS (differential GPS) corrections. Using the true, known position of the receiver antenna at each reference station, these land-based reference stations derive measurement corrections that adjust the GPS data to produce more accurate results. These measurement corrections are transmitted, for example, via minimum shift keying (MSK) transmissions, to the roving receivers as deviations or offsets to be added to the measurements derived by the roving receiver from the GPS signals received directly from the satellites. An example of such a system is the Differential GPS NAVSTAR system operated by the U.S. Coast Guard to help ships navigate more accurately.

To ensure that the corrections being broadcast by DGPS stations are useful, i.e., that the corrections are not providing inaccurate position determinations at the roving receivers, integrity monitoring stations have been established. As shown in FIG. 1, a DGPS integrity monitoring (IM) station **10** includes a receiver unit **12** having both GPS receiver circuitry and integral radio receiver circuitry. In other instances, the GPS receiver circuitry and radio circuitry may each comprise separate units. In either case, the radio receiver portion of DGPS IM station **10** receives the DGPS corrections as they are being broadcast by the DGPS station **14** to rover units **22** and provides these corrections to the GPS receiver circuitry. The GPS receiver circuitry of DGPS IM station **10** also receives GPS signals from orbiting GPS satellites **16** in the conventional manner and computes its position using the GPS data from those signals and the DGPS corrections provided by the radio receiver circuitry. The position obtained as a result of these calculations is compared to a known reference position **18** of the IM station **10** (e.g., as determined from a precise survey) and an error which represents the difference between the GPS computed position of the IM station **10** from its known location is derived (e.g., by a computer system **20** associated with the IM station **10**). If the error between the known location **18** and the GPS computed location of the IM station **10** station is not within acceptable user established tolerances, the IM station **10** may report an alarm condition to the DGPS station **14** operators. This may alert the operators of the DGPS station **14** that inaccurate DGPS corrections are being broadcast and that appropriate corrective action should be taken.

While DGPS techniques are suitable for applications requiring only sub-meter accuracy (e.g., shipboard navigation and the like), they are not suitable for applications requiring precise positioning (e.g., on the order of ±1 cm.) because of the techniques used to obtain this accuracy. Precise positioning applications, for example machine control applications and the like, require the use of real-time kinematic (RTK) GPS techniques. RTK receivers use locally collected GPS signals broadcast by GPS satellites along with reference carrier-phase and code-phase signals transmitted from RTK reference stations to compute position results down to the centimeter level. Unlike the DGPS corrections broadcast by DGPS reference stations, the signals transmitted by the RTK reference stations (hereafter referred to as RTK GPS data) are specially formatted messages which include various satellite observables (e.g., carrier phase and pseudorange measurements) as seen by the RTK reference station.

Rather than computing positions by simply developing pseudoranges to each visible satellite based on the times codes being transmitted by the satellites, extremely accurate GPS receivers, such as RTK GPS receivers, utilize phase measurements of the radio carriers received from various GPS satellites to compute positions. However, this position determination technique requires that so-called integer ambiguities be resolved by the GPS receiver. The integer ambiguities result from the fact that the receiver must compute the number of 360° carrier phase shifts between itself and the GPS satellite, but each carrier cycle appears identical to the receiver. Sometimes, an RTK GPS receiver will produce a "bad fix" because the receiver failed to properly compute the correct number of integer phase shifts between itself and the GPS satellite(s). As a result, the receiver will report a ("bad") position that is based on a calculation which places the receiver either too close to or too far from the satellite.

As a result of the differences between RTK GPS receivers and other GPS receivers, the solution adopted by the DGPS community for integrity monitoring is unsuitable for RTK applications. To illustrate, consider that DGPS IM stations rely on the fact that the corrections being broadcast by a DGPS reference station are generally applicable to all roving GPS receivers operating in proximity to (e.g., up to approximately 300 miles from) the DGPS reference station. Thus, the DGPS IM station operating within a given area need only monitor the DGPS corrections being broadcast for that area and compute its GPS position accordingly. However, RTK GPS receivers must initialize to a selected group of integer carrier phase shifts for a selected group of satellites to obtain a position fix and there can be no guarantee that an RTK GPS receiver at an IM station has initialized to the same set of integer carrier phase shifts for these satellites as a roving receiver, especially if the roving receiver is operating in an area having a different visible sky from that seen at the RTK IM station. Because of these differences, position computations at a roving receiver may be different than position computations at an RTK GPS receiver at an IM station and, thus, the RTK IM station may not provide an accurate indication of the reliability of the RTK position at the rover.

For these reasons, an improved integrity monitoring scheme for RTK GPS applications is desired.

SUMMARY OF THE INVENTION

In one embodiment, the present invention provides a method which includes computing a position of a first receiver using data from sources chosen according to conditions at a second receiver and reference data. The computed position is compared with a known position of the first receiver. The data from the sources may be GPS positioning data and the reference data may be RTK GPS data. The reference data may be provided by an RTK GPS reference station, for example via radio link. The conditions at the second receiver generally correspond to satellite constellations and the position of the first receiver may be computed by configuring the first receiver to mimic the second receiver by initializing to the same satellite constellations. These conditions may be further augmented by one or more site parameter characteristics for the second receiver, such as signal-to-noise ratio for each satellite of the satellite constellations, rover vehicle attitude, and other parameters.

The comparison of the computed position to the known position may result in an error measurement being produced, the error measurement representing an offset between the computed position and the known position of the first receiver. This error measurement may be used to initiate an alert condition if the error measurement exceeds a preestablished threshold value.

In a further embodiment, the present invention provides a receiver having first circuitry configured to compute a position of the receiver using data from sources chosen according conditions at a remote receiver and reference data. The receiver may further include second circuitry for comparing the computed position with a known position. The first circuitry may include a GPS engine which is configured to compute the position from GPS data derived from the sources. The sources may be GPS satellites and or pseudolites.

In yet another embodiment, the present invention provides a system including a first unit and a second unit, the second unit being configured to compute its position using data from sources chosen according to conditions at the first unit and reference data. The system may also include a reference unit configured to provide the reference data to the second unit. Preferably, the reference data is RTK GPS data.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which:

FIG. **1** illustrates a DGPS system including a DGPS integrity monitoring station;

FIG. **2** illustrates a system having an RTK integrity monitoring station configured according to one embodiment of the present invention;

FIG. **3** illustrates an exemplary routine for creating and transmitting RTK GPS data according to an embodiment of the present invention;

FIG. **4** illustrates an RTK reference station for use according to one embodiment of the present invention;

FIG. **5** illustrates an RTK integrity monitoring station configured according to one embodiment to the present invention;

FIG. **6** is a flow diagram illustrating a variety of routines for performing integrity monitoring and control functions in accordance with one embodiment of the present invention;

FIG. **7** illustrates a rover unit configured according to one embodiment of the present invention;

FIG. **8** is a flow diagram illustrating a routine for controlling operations at a rover unit in accordance with an embodiment of the present invention;

FIG. **9** illustrates a radio repeater for use according to an embodiment of the present invention; and

FIG. **10** illustrates a rover unit configured as a mobile integrity monitor station according to a further embodiment of the present invention.

DETAILED DESCRIPTION

Described herein is a Real-Time Kinematic (RTK) Integrity Monitor (IM). In one embodiment, a position of a first receiver may be computed using data from sources chosen according to conditions at a second receiver and reference data. The computed position is compared with a known position of the first receiver. The data from the sources may be GPS positioning data and the reference data may be RTK GPS data. The reference data may be provided by an RTK GPS reference station, for example via a radio or other link.

The conditions at the second receiver generally correspond to satellite constellations and the position of the first receiver may be computed by configuring the first receiver to mimic the second receiver by initializing to the satellite constellations and, in one embodiment, to one or more site parameter characteristics such as signal-to-noise ratio for each satellite of the satellite constellations, rover vehicle attitude, and other parameters for the second receiver. The comparison of the computed position to the known position may result in an error measurement being produced, the error measurement representing an offset between the computed position and the known position of the first receiver. This error measurement may be used to initiate an alert condition if the error measurement exceed a preestablished threshold value.

In a further embodiment, the present invention provides a receiver having fist circuitry configured to compute a position of the receiver using data from sources chosen according conditions at a remote receiver and reference data. The receiver may further include second circuitry for comparing the computed position with a known position. The first circuitry may include a GPS engine which is configured to compute the position from GPS data derived from the sources. The sources may be GPS satellites and or pseudolites.

In yet another embodiment, the present invention provides a system including a first unit and a second unit, the second unit being configured to compute its position using data from sources chosen according to conditions at the first unit and reference data. The system may also include a reference unit configured to provide the reference data to the second unit. Preferably, the reference data is RTK GPS data.

Although the methods and apparatus of the present invention are hereafter described with reference to GPS satellites, it will be appreciated that the teachings are equally applicable to positioning systems which utilize pseudolites or a combination of satellites and pseudolites. Pseudolites are ground based transmitters which broadcast a PRN code (similar to a GPS signal) modulated on an L-band (or other) carrier signal, generally synchronized with GPS time. Each transmitter may be assigned a unique PRN code so as to permit identification by a remote receiver. Pseudolites are useful in situations where GPS signals from an orbiting satellite might be unavailable, such as in tunnels, mines, buildings or other enclosed or semi-enclosed areas. The term

"satellite", as used herein, is intended to include pseudolites or equivalents of pseudolites, and the terms GPS signals and/or GPS data, as used herein, are intended to include GPS-like signals and/or data from pseudolites or equivalents of pseudolites.

It will be further appreciated that the methods and apparatus of the present invention may be equally applicable for use with the GLONASS and/or other satellite-based positioning systems. The GLONASS system differs from the GPS system in that the emissions from different satellites are differentiated from one another by utilizing slightly different carrier frequencies, rather than utilizing different pseudo-random codes.

It should be recognized that the integrity measurements provided by the present invention are best understood as estimates because the integrity monitor can only mimic the actual conditions being experienced at a rover. This, in turn, means that the integrity monitor can only achieve an estimate of the RTK GPS data integrity being received at the rover. Nevertheless, the present invention provides an improved ability to monitor RTK GPS data being broadcast to rover units and therefore may find application in a variety of situations where extremely precise GPS receivers are employed.

FIG. **2** illustrates a system **100** configured according to one embodiment of the present invention. In particular, system **100** includes a base station **102** located at a convenient site. Base station **102** includes an RTK GPS reference station **104** configured to provide RTK GPS reference data in the conventional fashion. Base station **102** also includes an RTK integrity monitoring (IM) station **106** configured to compute its location using data from GPS sources, for example, GPS satellites and/or pseudolites, chosen according to conditions at a remote unit and reference data provided by GPS reference station **104**. The reference data may be provided across a link **108** between reference station **104** and IM station **106**. Preferably, link **108** is a radio link (to more accurately simulate the rover conditions) although in other embodiments a hard wire link (or both) may be used.

System **100** also includes a number of rover units **110**. Each rover unit **110** includes an RTK GPS receiver and generally operates in an area of interest. For example, rover units **110** may each be housed on various equipments (e.g., earth moving equipment, command or other vehicles, etc.) operating at a mine or construction site or within an agricultural field. Many other examples of RTK rover units can be realized, for example automobiles, individuals (e.g., surveyors) and other uses.

Rover units **110** are each configured to receive RTK GPS data from reference station **104** to assist in precise position determination. In one embodiment, the data link **112** between reference station **104** and rover units **110** may be a radio link with sufficient bandwidth to provide the updates required for the precise positioning calculations performed by rover units **110**. The RTK GPS data may be provided in a format such as the compact measurement record (CMR) format described by Dr. Nicholas C. Talbot in "Compact Data Transmission Standard for High Precision GPS", Journal of the Institute of Navigation, September 1996. The CMR format encompasses both a message protocol and a compression/decompression algorithm for the reference data. CMR message blocks are packetized in frames and generally include header information along with satellite observable information (e.g., carrier phase and pseudorange measurements) as seen at reference station **104**. Observables are transmitted from reference station **104** approximately once every second and reference station location and station description messages may be sent once every ten seconds. In general, the CMR message blocks contain all the information necessary for rover units **110** to compute their positions to centimeter accuracy. Another format which could be used is RTCM 2.1, however, this would require additional radio bandwidth because of the relatively large message format as compared to the CMR format.

Radio link **112** is generally a line of sight radio link and may require the use of radio repeaters **114** where no direct line of sight exists between reference station **104** and rover units **110**. Such conditions may, for example, be encountered in mining operations where reference station **104** is positioned at an elevated location while rover units **110** are operating within the mine. Depending on the depth of the mine, rover units **110** may be out of sight of reference station **104**, thereby requiring the use of repeaters **114**.

In addition to rover units **110**, system **100** may include various stationary units **116**, each having an RTK GPS receiver. Stationary units **116** may correspond to, for example, offices located within the mine or other area of interest or, for example, may be operating platforms for which precise positions are required (e.g., drilling platforms). In addition, one or more stationary units **116** may correspond to rover units configured as remote integrity monitors as further described below.

As shown in FIG. **2**, radio link **112** of system **110** maybe a two-way radio link between rover units **110** and/or stationary units **116** and base station **102**. In such cases, in addition to RTK GPS data being transmitted from reference station **104**, data may be transmitted from any of rover units **110** and/or stationary units **116** to base station **102** across radio link **112**. In other embodiments, the link from rover units **110** and/or stationary units **116** to base station **102** may be a separate radio link.

The data provided by rover units **110** and/or stationary units **116** to base station **102** is formatted and includes information necessary to allow IM station **106** to compute its position using GPS sources chosen according to the conditions being experienced at the rover units **110** and/or stationary units **116**. That is, a given rover unit **110** may transmit data to IM station **106** across radio link **112**, that data including information necessary for IM station **106** to mimic the conditions being experienced at the transmitting rover unit **110**. In particular, the data transmitted by rover unit **110** may include satellite identification information which allows IM station **106** to identify the particular satellite constellation to which the transmitting rover unit **110** has initialized. Such data may further include signal strength information for each satellite and other "site parameter" information such as rover position, attitude and/or other parameters. These site parameters may be used by the IM station **106** to position the rover units within a virtual model of the operating area and may further be used to predict multipath transmissions (e.g., by knowing that a rover is at a certain attitude with respect to a nearby reflecting surface such as a building) which may affect position calculation. By knowing the particular satellites (and other site parameters) which the transmitting rover unit **110** has used to compute its position, IM station **106**, which includes a GPS receiver, may compute its own position using those same satellites. This allows IM station **106** to mimic the conditions being experienced at rover unit **110**, even though IM station **106** may be capable of receiving signals from satellites other than those used by rover unit **110**.

By mimicking the conditions being experienced at the transmitting rover unit **110**, IM station **106** may then use the

RTK GPS data provided by reference station **104** to compute its position. This computed position may be compared against a known position of IM station **106** (e.g., as determined by a precise survey) and an error produced thereby. The error will be a measurement of the difference between the computed position of IM station **106** (i.e., the position computed using GPS data as derived by mimicking the conditions being experienced at rover unit **110** and the reference data provided by reference station **104**) and the known location. This comparison may be performed using dedicated circuitry at IM station **106** or it may be performed using a general purpose programmable microprocessor running suitable software. Because IM station **106** initialized to the same satellites as transmitting rover unit **110**, the error derived at IM station **110** will provide an indication of the reliability of the RTK data being broadcast from reference station **104** to the transmitting rover unit **110**.

FIG. **3** illustrates an exemplary routine **200** for creating and transmitting RTK GPS data at reference station **104**. Routine **200** may be implemented on a general purpose programmable processor operating at reference station **104**. Such an embodiment would be realized using programming techniques well known in the art. In other embodiments routine **200**, or selected portions thereof, may be implemented in dedicated hardware and/or selectively programmed programmable logic. Such implementation details are essentially design choices and are often dictated by cost and/or board space considerations.

Routine **200** is essentially a loop where, so long as power is applied to the system, reference station **104** continually takes GPS measurements (step **202**), creates RTK GPS data messages therefrom, e.g., according to the CMR format (step **204**), and transmits those messages over radio link **112**. Such a loop ensures that RTK GPS messages are continually provided, e.g., typically once per second. These messages may be augmented by demi-measurements at the rover units **110** to produce position updates at a rate of 10 Hz or more. Such an update rate allows for precise machine control.

FIG. **4** further illustrates reference station **104** in greater detail. Reference station **104** includes a GPS receiver **120** having an associated GPS antenna **122**. GPS receiver **120** is coupled to radio **124** which is used for transmitting RTK GPS data developed by GPS receiver **120** across radio link **112**. Radio **124** may be a dual port radio which is configured to communicate with GPS receiver **120** as well as IM station **106**. GPS receiver **120** may include the general purpose processor or other programmable logic which implements routine **200** of FIG. **3**.

FIG. **5** further illustrates IM station **106**. IM station **106** includes a GPS engine **126** coupled to receive GPS data from GPS receiver **120** which is coupled to GPS antenna **122**. GPS engine **126** is also coupled to integrity monitor **128** which is also coupled to receive a position solution from GPS receiver **120**. Integrity monitor **128** is further coupled to the second port of radio **124**, allowing integrity monitor **128** to receive transmissions from rovers **110** and stationary units **116**. In operation, a transmitting rover unit **110** provides satellite identification information (and other site parameters) across radio link **112** to integrity monitor **128**. Integrity monitor **128** provides this information to GPS receiver **120** which takes a GPS fix using the indicated satellites. This fix data along with RTK GPS data from reference station **104** may be provided to GPS engine **126** which computes a position solution. Thus, the position solution is based upon conditions being experienced by a transmitting rover unit **110**. Integrity monitor **128** then compares this computed position with the known location of GPS antenna **122** to determine an error. The error may be reported from integrity monitor **128** across radio link **112** to the transmitting rover unit **110**.

As discussed above, IM station **106** may also be configured to maintain a virtual model of the area in which the rovers **110** and stationary units **116** are operating. This may be accomplished by having the rovers **110** and stationary units **116** provide IM station **106** with their respective GPS positions, e.g., as one of the site parameters to be transmitted to the IM station **106**. These position indications may be associated with other data identifying the transmitting rover **110** or stationary unit **116** and may be overlaid on a digital map of the operating area using programming techniques well known in the art. For example, conventional mapping or GIS programming techniques and data structures may be implemented to establish the digital model of the operating area.

FIG. **6** illustrates one possible set of routines which may be executed by one or more processors or other programmable devices which make up IM station **106**. Of course, many other routines which implement similar functionality could be devised and, therefore, the set of routines shown in FIG. **6** should be regarded as illustrative of the various processes performed at IM station **106** only. As shown, IM station **106** implements an integrity monitor routine **300**, a GPS measurement routine **400** and a control routine **500**. Each of these routines communicate with each other to pass data and control information and thereby achieve the desired functionality. Each of these routines is discussed below.

Integrity monitor routine **300** compares a computed GPS position with a known position for the IM station **106** and provides an error message indicating the difference between these two positions in response thereto. The routine begins at step **302** where data (such as satellite information, rover position and other site parameters) is received from a rover **110** via radio link **112**. This data may be provided to GPS measurement routine **400** as discussed below and may also be provided to a virtual model routine running on IM station **106** to position the rover **110** in the virtual model. Further, the satellite information is provided to GPS receiver **120**. Using the satellite information, at step **304** GPS receiver **120** is configured to take a fix using the same satellites as are being used by rover **110**. The fix is then taken and the GPS data derived therefrom is passed to routine **300** from GPS receiver **120** at step **306**.

At step **308** (which may be performed substantially in parallel with step **306** in some embodiments), routine **300** receives RTK GPS data from reference station **104**. This may be accomplished across radio link **112** where IM station **106** has a separate radio **130** (see FIG. **5**) for receiving such messages. In other embodiments, the RTK GPS data may be provided across a dedicated (e.g. a hard wire) link. At step **310**, routine **300** passes the GPS data from step **306** and the RTK GPS data from step **308** to GPS measurement routine **400** to compute a GPS position for IM station **106**. This computation may be performed in the conventional fashion or using the other rover site parameters as described below and the output GPS position is reported to integrity monitor routine **300** at step **312**.

At step **314**, integrity monitor routine **300** compares the computed GPS position with the known position of IM station **106**. The result of this comparison is used to generate an error message representing the difference between the computed GPS position and the known position. This error message may then be reported to the rover **110** and to the control routine **500** at step **316**. The integrity monitor routine **300** then returns and waits to receive a new set of rover data.

GPS measurement routine **400** computes a GPS position for IM station **106** using GPS data derived from measurements taken by GPS receiver **120** and RTK GPS data from reference station **104**. The routine first receives the computed position solution from integrity monitor routine **300** at step **402**. Then, at step **404**, the routine configures GPS engine **126** in accordance with the various rover site parameters received from the integrity monitor routine. This may include weighting the GPS measurements from GPS receiver **120** differently, according to reported signal-to-noise ratios from rover **110**. Further, other weightings may be applied according to rover attitude, etc. This step is optional and in some embodiments will not be performed.

At step **406**, the routine instructs GPS engine **126** to compute the GPS position of IM station **106** based on the above configuration, the GPS data from GPS receiver **120** and the RTK GPS data from reference station **104**. This computed position is then reported to the integrity monitor routine **300** at step **408**.

Control routine **500** receives the error message from integrity monitor routine **300** at step **502**. Based on this message, appropriate alarm conditions may be generated and/or displayed at step **504**. At step **506**, the error message and/or alarm flags may be used to initiate appropriate control instructions, e.g., if the reported error exceeds preestablished thresholds. This may include automatically switching control to an alternate RTK reference station.

FIG. **7** illustrates an exemplary rover unit **110**. Each rover unit **110** will typically include a GPS receiver **150** having an associated GPS antenna **152**. GPS receiver **150** is configured as an RTK GPS receiver which is capable of receiving RTK GPS data through an associated radio **154**. Such RTK GPS receivers are well known in the art. GPS receiver **150** is further capable of determining which satellites have been used for initialization (i.e., which satellites are being used for computing its position) and is configured to transmit that information across radio link **112** using radio **154** to IM station **106**. Further, the rover **110** may be configured to report other site parameters, as described above. This information will allow IM station **106** to configure itself so as to mimic the conditions being experienced at rover unit **110** and may further allow IM station **106** to construct the virtual model of the operating area.

Rover unit **110** may further include an application engine **156**. Application engine **156** will use the position information received from GPS receiver **150** as well as error information produced by IM station **106** to determine whether positions which are computed at rover unit **110** are within acceptable tolerances. That is, if the error exceeds a predetermined threshold, application engine **156** may recognize an alarm condition and report same to an operator associated with rover unit **110**.

FIG. **8** illustrates a routine **600** which may be executed by one or more processors and/or other dedicated or programmable logic at rover unit **110**. Routine **600** begins at step **602** where GPS measurements are taken by GPS receiver **150**. At step **604** (which may be performed substantially in parallel with step **602** in some embodiments), rover **110** receives RTK GPS data from reference station **104** across radio link **112**. This RTK GPS data, together with the GPS measurement data from step **602**, is used to compute a position of rover **110** at step **606**. At step **608**, the satellite information used to compute this position may be passed to application engine **156** for further use.

Application engine **156** continues the operations defined by routine **600** and at step **610** transmits the satellite information (and other rover site parameters, e.g., signal-to-noise ratios for each satellite, rover position and/or attitude, etc., if desired) from step **606** to the IM station **106**. As described above, IM station **106** uses this information to compute an error message which is returned to rover **110** at step **612**. Based on the error message, at step **614** alarm conditions may be reported, e.g., if the position error exceeds preestablished thresholds. These error conditions may be acted on by other processing elements or routines within application engine **156**. If no errors are reported, routine **600** continues to execute, thereby monitoring the position solutions provided by GPS receiver **150**.

FIG. **9** further illustrates the optional radio repeater **114**. Radio repeater **114** may be a conventional repeater which includes a radio **160** and a power supply **162**. The radio **160** is configured to receive and relay messages on radio link **112** between rovers **110** and/or stationary units **116** and base station **102**.

FIG. **10** illustrates a rover unit which is configured as a mobile integrity monitor **170**. Mobile integrity monitor **170** includes GPS receiver **172** and an associated GPS antenna **174**. Mobile integrity monitor **170** also includes a radio **176** capable of interfacing to radio link **112**. In operation, mobile integrity monitor **170** may be positioned over a known point **178** and left stationary for sometime. Over time, GPS receiver **172** will derive a highly accurate position of mobile integrity monitor **170** using conventional GPS surveying techniques. This highly accurate position may be compared against the known position of point **178** and an error determined thereby. This error can be used as a check on the RTK GPS data being provided by base station **102** across radio link **112**. Moreover, the mobile integrity monitor **170** may be used as a regular IM station and the other rover units **110** may transmit data to the mobile integrity monitor **170** as for IM station **106**. In some situations, a mobile integrity monitor **170** may be able to provide a better integrity estimation of the RTK GPS data being broadcast to the rovers **110** than is provided by IM station **106**. This may be because, in general, mobile integrity monitor **170** will be operating under conditions more closely resembling those experienced by the rovers **110** due to its physical proximity to the rovers **110** within the operating area. This physical proximity may provide for more real-world conditions (e.g., multipath) than can effectively be mimicked at IM station **106**.

Thus, a real-time kinematic integrity monitor has been described. Although described with reference to certain specific illustrated embodiments, those skilled in the art will appreciate that the present invention may find application in a variety of precise positioning determination systems. Accordingly, the present invention should only be measured in terms of the claims which follow.

What is claimed is:

1. A method comprising the steps of:

computing a position of a first receiver using Global Positioning System (GPS) positioning data from sources chosen according to conditions at a second receiver, said conditions having been specified by data transmitted from said second receiver to said first receiver, and real-time kinematic (RTK) GPS reference data provided by an RTK GPS reference station; and

comparing said computed position with a known position of said first receiver.

2. A method as in claim **1** wherein said conditions comprise particular satellite constellations.

3. A method as in claim **2** wherein said conditions further comprise signal-to-noise ratios for said satellite constella-

tions and attitude information for a rover unit associated with said second receiver.

4. A method as in claim 2 wherein said step of computing further comprises configuring said first receiver to mimic said second receiver by initializing to said satellite constellations.

5. A method as in claim 4 wherein said reference data is provided via radio link.

6. A method as in claim 5 wherein said step of comparing further comprises determining an error measurement representing an offset between said computed position and said known position.

7. A method as in claim 6 further comprising initiating an alert condition if said error measurement exceeds a preestablished threshold value.

8. A method as in claim 6 further comprising transmitting said error measurement to said second receiver.

9. A method as in claim 8 further comprising initiating an alert condition at said second receiver if said error measurement exceeds a preestablished threshold.

10. A receiver comprising first circuitry configured to compute a position of said receiver using data from sources chosen according to conditions at a remote receiver, said conditions having been specified by data transmitted from said remote receiver to said receiver, and real-time kinematic (RTK) global positioning system (GPS) reference data.

11. A receiver as in claim 10 further comprising second circuitry for comparing said computed position with a known position of said receiver.

12. A receiver as in claim 11 wherein said first circuitry further comprises a GPS engine configured to compute said position from GPS data from said sources.

13. A receiver as in claim 12 wherein said first circuitry further includes a radio configured to provide said reference data to said GPS engine.

14. A receiver as in claim 13 wherein said radio is configured to receive said reference data from a reference station.

15. A receiver as in claim 14 wherein said second circuitry comprises a general purpose programmable microprocessor.

16. A receiver as in claim 15 wherein at least one of said sources is a GPS satellite.

17. A receiver as in claim 15 wherein at least one of said sources is a pseudolite.

18. A method as in claim 16 wherein said data transmitted from said remote receiver includes source identification information.

19. A method as in claim 18 wherein said data transmitted from said remote receiver further includes signal strength information for signals received at said remote receiver from said sources.

20. A system comprising:

a first unit configured to transmit data specifying conditions being experienced at said first unit; and

a second unit configured to compute a position of said second unit using data from sources chosen according to said conditions at said first unit and real-time kinematic (RTK) global positioning system (GPS) reference data.

21. A system as in claim 20 further comprising a reference unit configured to provide said reference data.

22. A system as in claim 21 wherein said data specifying conditions comprises satellite identification information.

23. A system as in claim 22 wherein said second unit is further configured to compare said computed position to a known position of said second unit.

24. A system as in claim 23 wherein said second unit is further configured to report a result of a comparison of said computed position to said known position to said first unit.

25. A system as in claim 24 wherein said first unit is further configured to report an alarm condition when said result exceeds a predetermined threshold value.

26. A system as in claim 25 wherein said first unit further comprises an RTK GPS receiver.

27. A system as in claim 24 wherein said second unit further comprises a GPS engine configured to compute said position of said second unit according to said satellite identification information.

28. A system as in claim 27 further comprising a first radio link between said first unit and said second unit.

29. A system as in claim 28 further comprising a second radio link between said reference unit and said first unit.

30. A system as in claim 29 further comprising a third radio link between said reference unit and said second unit.

31. A system as in claim 30 wherein said first radio link between said first unit and said second unit includes a repeater unit configured to relay messages between said first unit and said second unit.

32. A system as in claim 31 wherein said messages include said satellite identification information.

33. A system as in claim 32 where in s aid messages further include said result of said comparison.

34. A system as in claim 33 wherein said repeater unit is further configured to relay said reference data between said reference unit and said first unit.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,936,573

DATED : August 10, 1999

INVENTOR(S) : Derek Steven Smith

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 4 at line 39, delete "fist" and insert --first--

Signed and Sealed this

Twentieth Day of March, 2001

Nicholas P. Godici

Attest:

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office